

## SPACE SHUTTLE ONBOARD NAVIGATION CONSOLE EXPERT/TRAINER SYSTEM

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### ABSTRACT

This paper describes a software system (ONAV) under development at NASA's Johnson Space Center in Houston for use in enhancing operational performance as well as training ground controllers in monitoring onboard Space Shuttle navigation sensors. Previous expert system development work at NASA Johnson has shown that mainstream expert system development must follow a mix of software and system engineering procedures to insure operational success and effectiveness. ONAV development reflects this trend toward following a structured and methodical approach to development. The ONAV system must deal with integrated conventional and expert system software, complex interfaces, and implementation limitations due to the target operational environment. An overview of the onboard navigation sensor monitoring function is presented, along with a description of guidelines driving the development effort, requirements that the system must meet, current progress, and future efforts.

### INTRODUCTION

This paper describes a Onboard Navigation (ONAV) software system under development at NASA's Johnson Space Center (JSC) for use in enhancing operational performance as well as training ground controllers in monitoring onboard Space Shuttle navigation sensors. Previous expert system development work at NASA JSC has shown that mainstream expert system development must follow a mix of software and system engineering procedures to ensure operational success and effectiveness. ONAV expert system development reflects this trend toward following a structured and methodical approach to development. The ONAV system must deal with integrated conventional and expert system software, complex interfaces, and implementation limitations due to the target operational environment. An overview of the onboard navigation sensor monitoring function is presented, along with a description of guidelines driving the development effort, requirements that the system must meet, current progress, and future efforts.

The Guidance and Onboard Navigation section (DM34) has a requirement to develop an expert/trainer system to assist in the training of Mission Control Center (MCC) onboard ONAV console operators during periods other than integrated simulations. This system is expected to evolve into a console assistant with the potential for increasing operations support effectiveness. The Space Shuttle Orbiter ONAV system is relatively stable and mature with limited new design/developments anticipated. The ONAV expert/trainer involves numerous aspects of current and future MCC functional elements including workstations, local area network (LAN) interfaces, telemetry (systems) and ground (trajectory) data, and crew and ground procedures. This situation ensures that the ONAV expert/trainer system, providing experience with a majority of the aspects of anticipated MCC functions, will benefit future Space Transportation System (STS) and Space Station operations.

### ONBOARD SPACE SHUTTLE NAVIGATION

The purpose of the ONAV system is to estimate the Space Shuttle Orbiter's position and velocity (called the state vector). This is done by computing or measuring vehicle acceleration and numerically integrating it to obtain velocity and position. At various times, position measurements from outside sources are used to improve the state vector estimate.

During the descent phase of Space Shuttle flight where the vehicle comes from Earth orbit down to a landing site, the navigation system uses several position measurements to improve position estimates. Drag altitude is a very rough measurement which uses inertial measurement unit (IMU) sensed acceleration and an atmosphere model to estimate the altitude. Tactical air navigation (TACAN) measures the slant range and magnetic bearing from a ground station to the Orbiter. The air data system uses air pressure probes to measure the static atmospheric pressure, and compute an altitude measurement called baro altitude. Finally, the microwave scan beam landing system (MSBLS) provides measurements of slant range, azimuth angles, and elevation angles from ground transmitter stations located near a runway.

To achieve some degree of fault tolerance, the Orbiter contains three redundant IMUs, three TACAN transceivers, four air data sensors, and three MSBLS transceivers. Each piece of hardware is called a line replaceable unit (LRU). For each of these hardware systems there is a redundancy management (RM) software program in the onboard Shuttle computers. The RM has the task of choosing one set of measurements from the available sources and detecting and isolating failures in the hardware.

## **THE ONBOARD NAVIGATION CONSOLE TASK**

The job of the ONAV console monitor is to assess the health of the various components of the ONAV system, and recommend actions to improve or maintain navigation accuracy. In performing this task, at entry ONAV uses onboard navigation data telemetered to the MCC, and the "ground state" (an independent estimate of the orbiter state.) The ground state is computed using ground radar measurements. IMU monitoring is based on comparisons of IMU attitude and velocity data, as well as comparisons with ground computed values. Possible recommendations include deselecting or reselecting IMUs. TACAN monitoring is based largely on comparisons of LRU measurements with the ground and with each other. Possible recommendations include using or not using TACAN data, deselecting or reselecting a TACAN LRU, or switching to a different TACAN station. ONAV has very little visibility into the air data system, so comparison of the baro altitude measurements with the ground is the main monitoring tool. Possible recommendations include using or not using baro altitude data. MSBLS monitoring is based on comparisons of LRU measurements with the ground and with each other. Possible recommendations include forcing TACAN to override MSBLS, or powering off a MSBLS LRU.

## **DEVELOPMENT GUIDELINES**

This section presents a brief description of the development guidelines that impact the ONAV expert system.

### **Problem Domain**

The ONAV expert system will consist of four distinct components corresponding to the following four Shuttle mission phases: ascent, onorbit, deorbit, and entry.

### **Knowledge Base**

Development of the rules for the ONAV system will be generated and documented as four separate knowledge bases corresponding to each mission phase. The expert system will incorporate the concept of modular design to logically partition both data and rules in order to promote and enhance program development and extensibility. The following sources of information will be utilized, as appropriate for ex-

pert system knowledge base development: ONAV console checklists, ONAV display user's guides, and ONAV console personnel.

## **Development Environment**

The expert system application software will be executable in a language available in a workstation environment. However, an expert system shell written in C called CLIPS will be used.

## **Documentation**

- a) Expert system software code: The expert system software will include comment text, to the maximum extent practical, according to proposed documentation standards for expert systems being developed at the JSC. Further, the comments will be enhanced through the use of long, descriptive variable names, labels, etc.
- b) Guidelines and system requirements: This document is a top level overview of the ONAV development effort. This information is critical to providing proper direction to the project. Availability of this information not only provides a means to communicate to others not involved in the project, but also serves as a historical document. For very complex and detailed efforts, such a document serves as the first step in maintaining traceability and configuration control of software products.
- c) Knowledge requirements: The target audience for this document is the knowledge domain expert. It is a reflection of "what the system knows" in a form as close as possible to the expert's language.
- d) Design: This document is intended for use by the implementers of the expert system and will serve as a guide for the coding effort. Contents will include such things as fact formats, data representation, rule groupings, control flow, execution flow, interfaces, etc.
- e) User's guide: The user's guide will present procedures for preparation, operation, monitoring, and recovery of the expert system. The user's guide will be based upon the design specification and is intended for the specific use of the users. It will include procedures for system operation directly in support of operational tasks.
- f) Test plan: The test plan defines the total scope of the testing to be performed. It identifies the particular levels of testing and describes the contributing role for ensuring the reliability and acceptance of the system. It identifies the degree of testing and the specific functions that are involved in the tests. The test plan is for

reviewing and ensuring that the technical requirements are met.

## Operation Modes

The ONAV expert system will operate in either of two modes. In the first mode, referred to as "closed loop," the system will be used with operational data. The operations environment will consist of integrated simulations. When the expert system is certified as accurate and reliable, it will be used in the actual mission environment. In the second mode, referred to as "open loop," the system will be used for initial level training and familiarization purposes using existing data tapes from several sources.

## Timing

The expert system will provide outputs in a real-time telemetry/trajectory environment and system timing will be structured accordingly. Real-time data rates will apply to the expert system as ported to the workstation environment and not apply to development machines, if different. The expert system will assume data is available at approximately 2 second intervals.

## Display Definitions

The primary function of the display will be to depict recommendations from the ONAV expert system to a ground controller. The goal is to provide an easily interpreted, quick-look format that shows the current status of the overall system, the status of individual subsystems, and recommended navigation system actions.

## DESIGN OVERVIEW

The overall environment in which the ONAV expert system will operate is illustrated in figure 1. Although different mission phases may have different functional structures, as an example, the ENTRY architecture for the expert system is depicted in figure 2. This structure results from the basic nature of the ONAV task at the descent phase of the mission. Four functional components of the expert system are identified: 1) fact assertion, 2) monitoring, 3) analysis, and 4) output. In addition, two non-expert system components which are a part of the overall ONAV system called "computations" and "data preparation" are also shown in both figures. The computations component receives information from the operational environment of the MCC LAN and performs various computations such as scaling, state vector propagation, coordinate system transformations, etc. The prime purpose is to make information uniform in time (i.e., homogeneous), which is not necessarily the case with raw data from the local area network. The data preparation component receives information from either the operational environment or training tapes and performs three functions: (a) collects the information required by the expert system, (b) performs any additional computations required on the

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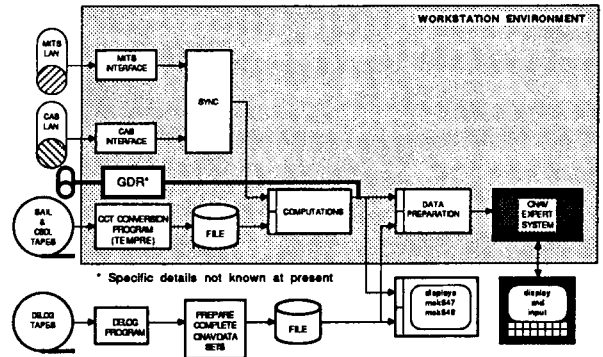


figure 1

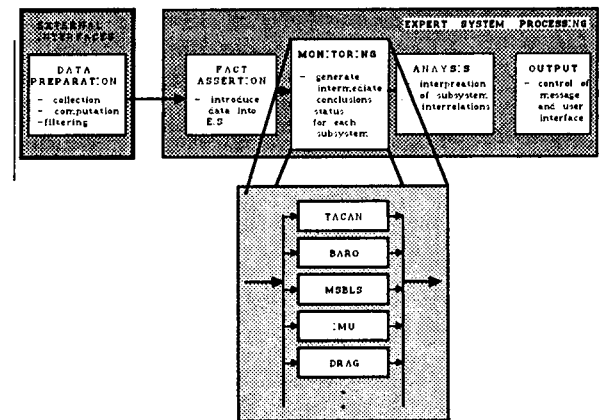


Figure 2

data, and (c) filters and transforms that data into a form suitable for the expert system. Non-discrete numeric data are compared to thresholds and converted to "symbolic" forms whenever possible.

The fact assertion component takes the prepared data and puts that required by the expert system into the expert system fact base and the remaining data into the C software environment for background processing and reference. The monitoring component generates intermediate conclusions and statuses of the individual subsystems ONAV observes and manages. The analysis component performs an overall assessment of the current situation taking into account interrelationships between subsystems. The output component controls the sending of notices and/or recommendations to the ONAV expert system console.

### **CURRENT PROGRESS AND FUTURE PLANS**

The ENTRY ONAV prototype was completed in June 87. A complete version of the ENTRY knowledge base design is currently under development. The ENTRY knowledge base line document was also completed and is waiting for final publication. The RENDEZVOUS ONAV is also well under way, a set of nominal rules are written and currently under design evaluation. Development work on the ascent phases of ONAV was initiated in July.

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